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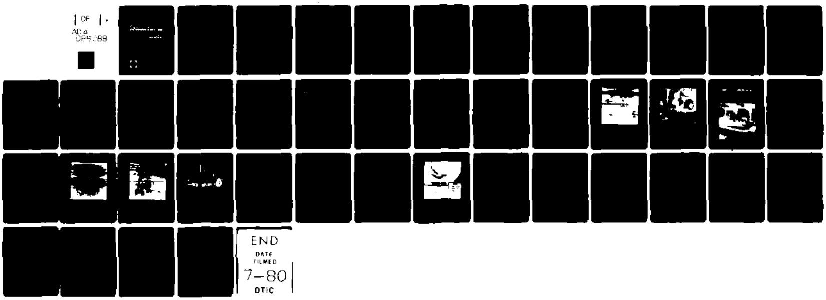

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author: P. S. Springston

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CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
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CONTENTS

INTRODUCTION AND BACKGROUND

Air Force Experience

The Air Force has been involved in research and development efforts to achieve a capability for rapidly repairing bomb-damaged runways. Currently, an established time constraint requires the identification and rehabilitation of a 50 by 5,000-foot runway to standards suitable for operation of aircraft within four hours after attack. For example, repair of three craters produced by 750-pound bombs should be completed within 4 hours.

With the present Air Force procedure (Ref 1), all broken pavement is removed, the crater is backfilled with broken pavement and crater ejecta to within 12 inches to 24 inches (NATO nations) of the original pavement surface, and this upper 12 to 24 inches is filled with compacted select base material (from previously stockpiled material). The compacted select base material is brought to the grade of the original pavement. AM-2 airfield landing mat is assembled on undamaged pavement near the crater and dragged over the filled crater after compaction has been completed.

The Air Force is presently studying effects upon aircraft of roughness induced by high-speed transitions from pavement to surface-mounted matting (1.5-inch bump height). There may be critical combinations of spacing and ground speed that would be hazardous to aircraft carrying external stores of munitions or wing-tip mounted fuel tanks.

Alternative Concept

This report documents the traffic testing of an alternative concept to AM-2 matting for a bomb crater cap – a fiberglass-reinforced polyester (FRP) membrane. Such a membrane is relatively thin and is, in effect, a flush-mounted cap. The Civil Engineering Laboratory (CEL) has conducted considerable research in the development of a system using fiberglass-reinforced polyester resin as an expedient beach and roadway surfacing material for vehicular traffic (Ref 2,3,4,5). The specialized chemicals and related equipment are known as the Advanced Multipurpose Surfacing System (AMSS).

A concept was developed during early FY79 which adapted AMSS technology to solve the problem of rapid runway repair (Ref 6). The concept consisted of a 1/2-inch-thick, prefabricated FRP membrane, which would be manufactured by military personnel during peacetime and would be shallow-buried adjacent to a runway. After an attack the membranes would be uncovered and towed over bomb craters backfilled with debris and crushed stone base course material. The membranes could be quickly cut to size to fit individual craters using carbide-tipped saw blades.

The FRP cap functions primarily as a cover to prevent the crushed stone from causing foreign object damage (F.O.D.) to aircraft although the cap serves to increase trafficability of the underlying base course through some distribution of wheel load.

One of the problems in the use of this cap was selection of the type of fastener needed to hold the cap and runway surface together. After consideration of several types of fasteners, a torque-set type of rock bolt was selected for fastening the FRP cap to undisturbed pavement around the crater perimeter. A test plan was written (Ref 7) and in late FY79 the FRP concept was traffic-tested under simulated F-4 and C-141 aircraft wheel loads at Tyndall AFB, Fla. with the assistance of the Research Division of the Air Force Engineering and Services Center.

OBJECTIVE

This report documents results of traffic testing of a 1/2-inch-thick FRP membrane. The membrane was trafficked by two load carts simulating the main gears of an F-4 aircraft (267-psi tire pressure and 27,000-pound single wheel load) and a C-141 aircraft (185-psi tire pressure and 141,000-pound twin-tandem wheel load). The trafficking was conducted with assistance from the Air Force Engineering and Services Center (AFESC) at Tyndall AFB, Fla. The test site consists of three 20 by 20-foot openings in a 12-inch-thick concrete pavement overlying a 6-ft-deep low-strength (CBR 4 to 6) clay subgrade (Ref 8). The trafficability of the FRP membrane concept for rapid runway repair (RRR) is evaluated herein, and recommendations are presented for further research.

DEFINITION OF TERMS

For information and clarity, certain terms used in this report are defined as follows:

Test section: The prepared area, including the surfacing for test purposes.

Traffic lane: Area of the surfacing that is subjected to the rolling wheel load of the load cart.

Subgrade: Soil processed under controlled conditions to provide the desired bearing capacity. The base course was placed on this.

California Bearing Ratio (CBR) : A measure of the bearing capacity of the soil based upon its shearing resistance. CBR is calculated by (1) dividing the unit load required to force a standardized piston into the soil at a standardized rate by the unit load required to force the same piston at the same rate into a standard sample of crushed stone and (2) then multiplying by 100.

Deflection: Temporary bending of the surfacing under the static load from the test wheel of the load cart.

Transverse dishing: Permanent bending of the surfacing perpendicular to the direction of traffic.

Longitudinal dishing (with reference to panel): Permanent bending of the surfacing parallel to the direction of traffic.

Direction of traffic: The direction in which the load cart travels on the test section. The direction of traffic is representative of actual landing directions with respect to construction joints.

Coverage: One application of the test wheel of the load cart over every point within the traffic lane.

Load cart: A specially constructed cart used in AFESC engineering tests for simulating aircraft taxiing operations.

Test wheel: The wheel on the load cart that supports the test load.

PRELIMINARY DESIGN

Prior to traffic testing, an investigation was conducted to optimize the design of FRP membrane and crushed stone base course topping (Ref 6). A finite element computer code, SLIP (Ref 9), developed by E. L. Wilson of the University of California and later modified by CEL was used to evaluate the effects of membrane and base course thicknesses on system performance. Close estimates of Young's modulus for the crushed limestone base course and clay subgrade materials which would be used in the traffic testing were required for accurate computer prediction of soil-membrane response. Samples of these soils were obtained from the AFESC and triaxial tested to determine response characteristics and representative moduli.

An iterative procedure was followed whereby the computer-predicted soil stress state was located on the appropriate soil stress-strain curve plotted from experimental data, and the elastic modulus was then put into the computer program and the code re-run. The sequence was iterated until moduli and stress states from experimental (triaxial) data matched those for the representative elements of the SLIP crater model.

The actual traffic section profile is depicted in Figure 1, and the idealized traffic section profile for computer analysis is presented in Figures 2 and 3. The final design specified a membrane of 1/2 inch and a base course depth of 24 inches. Initial static deflection beneath the F-4 wheel load for this system was estimated to be 0.25 inch with a predicted deflection basin as shown in Figure 4. The predicted soil-strain distribution is plotted in Figure 5. More complete information concerning the soil testing, computer analysis, and preliminary design is presented in Reference 6.

SUBGRADE PREPARATION, TESTING, AND INSTRUMENTATION

For trafficability testing, a fat clay (CH*) subgrade simulated the debris of a backfilled bomb crater. Physical properties and mineralogical composition of the clay are given in Tables 1 and 2. The clay subgrade was excavated to a depth of 24 inches below the surface elevation of the adjacent concrete, and moisture/density tests as well as tests to determine the CBR of the clay were conducted by AFESC personnel (Table 3). The average subgrade CBR in six tests was found to be 4.8%.

A 24-inch-thick lift of crushed limestone base course material with gradation (Figure 6) conforming to ASTM Test Designation D-2940 (Ref 11) was spread on the clay surface and compacted at a moisture content of 3.8%** by dry weight with a RAYGO 400 vibratory roller for 32 coverages. After final grading, moisture/density tests were again conducted, and the base course was instrumented with three pairs of soil strain gages.

The strain gages (Bison soil strain sensors) were placed in a vertical stack with sensors in parallel and coaxial alignment and with individual gages located at 6-inch intervals to a depth of 18 inches below the upper surface of the base course. Sensor cables were buried within the subgrade.

The soil strain sensors are manufactured by Bison Instruments, Inc., Minneapolis, Minn. The sensors are individual disk-shaped coils which operate through electromagnetic mutual inductance coupling of any two sensors. The sensors are not connected and are "free floating" in the soil; thus, they contribute minimal interference with soil movement. The sensors were connected by coaxial cable to a Bison Instruments Model 4101A Soil Strain Instrument which contained the driving, amplification, balancing, calibration, and recording controls, and a self-contained power supply. Although spacing resolution with this system was 0.0001 inch, laboratory bench tests indicated that spacing measurement was repeatable to within +0.0032 or -0.0030 inch.

MEMBRANE CONSTRUCTION

A 22-ft sq FRP membrane was fabricated on concrete adjacent to the test pit. The membrane was constructed of four layers of 4020-weight (40-oz/sq yd woven roving and 2-oz/sq ft chopped strand) fiberglass mat for a total finished membrane thickness of approximately 1/2 inch. Alternate layers of polyethylene, 15-lb roofing felt, and mold release paper separated the fiberglass mat from the concrete to prevent adherence of polyester resin to the concrete. The fiberglass is packaged in rolls having a width of 6-1/2 feet. Therefore, it was necessary to lap strips of fiberglass mat to achieve the finished membrane width of 22 feet. Adjacent fiberglass strips were overlapped by 8 inches to produce the membrane.

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*Classification by the Uniform Soil Classification System (Ref 10).

**Optimum was 6.0% by ASTM Test Designation D698-70, Method C, Ref 12.

Two layers of fiberglass were positioned and saturated with polyester resin (PPG Industries RS 50338) and immediately rolled with an aluminum roller to expel air trapped in the laminate. A third layer of fiberglass next was positioned, saturated with resin, and rolled. Repeat of the procedure for a fourth layer of fiberglass completed membrane construction (Figure 7).

During fabrication the volumes of catalyst and promoter which were mixed with the polyester resin were carefully controlled to provide a slow cure of the resin. Time to gelation was approximately 1 hour. The final layer of fiberglass was saturated with resin before resin curing had begun in the previous layers. A long gel time is critical since less shrinkage of the laminate is associated with a slow cure. Furthermore, gelation did not begin until all fiberglass had been positioned, thus providing the membrane with sufficient weight to prevent warping, which would have accompanied a fast cure and low laminate weight.

After fabrication, a towbar was bolted to one edge of the membrane and a 2-1/2-cu-yd capacity front-end loader towed the membrane across the test pit (Figure 8). The membrane was secured to the concrete pavement with 1/2 x 3-in. torque-set type rock bolts (Figure 9) manufactured by the Rawlplug Co. of New Rochelle, N.Y. The bolts were placed at 4 feet on-center along the membrane perimeter. Holes of 5/8-in.-diam were drilled in the concrete with a Rockwell rotary hammer to accommodate the bolts.* Two 4-in.-sq pieces of fiberglass mat were laminated to the membrane at each bolt location to locally strengthen the mat and to provide a flush surface at bolt heads.

TRAFFIC TESTING

A specially designed load cart (Figure 10) loaded to 27,000 pounds was used for simulation of a main gear of a fully loaded F-4 aircraft. The load cart is constructed with an outrigger wheel to prevent overturning and is powered by a front-wheel-drive truck. The load cart was equipped with a 30-7.7, 18-PR tire inflated to 265 psi. With the 27,000-lb wheel load, the tire has a contact area of about 102 sq in.

A traffic distribution pattern that would be encountered in actual runway operations was simulated. The pattern approaches a statistically normal distribution curve (Ref 13). Traffic started on one side of the test lane, and the load cart was driven forward and then backward in the same path for the length of the traffic lane. The path of the cart was shifted laterally 10 inches (the width of the tire print) on each successive forward trip. The interior 100 inches of the traffic lane was trafficked to six additional coverages. The center 60 inches of the traffic lane received two additional coverages for a total of ten coverages. The net result was that the center 60-in.-wide strip of the traffic lane

*The holes were inadvertently drilled to 5/8-in.-diam instead of the correct diameter of 1/2 inch. Several of these incorrectly installed bolts worked loose because of the moving wheel load. After the bolts were replaced in properly sized holes, they held properly, and no further problems were noted.

received 100% of the traffic, the 20-in. wide strips on either side of the center 60-in. strip received 80%, and the 10-in.-wide outside strips received only 20% of traffic (Figure 11).

At intervals of 0, 80, 100, and 150 coverages, the following data were recorded for the test section:

1. Static deflection beneath the test wheel
2. Soil strain beneath the test wheel
3. Permanent deformation, including longitudinal and cross section profiles

The locations for data recording are shown in Figure 12.

After application of 80 coverages of the F-4 load cart, the crushed stone of the test section had compacted uniformly, without rutting, by approximately 1 inch (Figure 13). To demonstrate relocatability of the FRP membrane, it was removed from the test section, and 1-1/2 cu yd of crushed limestone was added, compacted, and graded to return the crushed stone to the grade of the surrounding concrete pavement. The FRP membrane was removed by unfastening the nuts from the tie-down bolts, placing a 6-in. x 6-in. x 20-ft FRP angle section under each of the two sides for skids and dragging the membrane off the test section. After final grading of the crushed stone, the membrane was dragged back over the test section and re-bolted to the concrete. Traffic was then continued for a total of 150 coverages (maximum specified by the AFESC) of the F-4 load cart (Figure 14).

After completion of trafficking with the F-4 load cart, an additional 20 coverages (specified by the AFESC) of traffic were applied to the test section with a load cart simulating a main gear of a C-141 aircraft (Figure 15). The cart contains a twin-tandem type gear having 4 tires inflated to 185 psi with a total gear load of 141,000 pounds. C-141 load cart traffic was applied in a distributed pattern (Figure 16).

TRAFFICABILITY

In summary, the FRP membrane performed exceptionally well under both the F-4 and C-141 load cart traffic. After 150 coverages with the F-4 load cart and 20 coverages with the C-141 load cart, the membrane (including the transitions from concrete to the membrane) remained completely serviceable and without any indication of any failure or wear. By 80 coverages of the F-4 cart, the crushed stone base course had densified such that its surface was approximately 1 inch below that of surrounding pavement (Figures 17 and 18). The membrane, however, had prevented any rutting of the base course (Figure 13). Thus, the densification indicated an increase in base course strength. The test section was readily restored to the proper grade by removal of the membrane and by addition of 1-1/2 cu yd of crushed limestone.

Soil strain data were recorded for the initial static load of the F-4 tire. Prior to trafficking, the load cart tire was positioned directly over the soil strain gages, and data were recorded. The strain data from this initial static loading were the only data which could be meaningfully compared with analytical predictions derived from using SLIP which solves only linear-elastic, static problems. Good correlation was noted between the experimental data and the SLIP-predicted soil strain (Ref 6) for the load centerline location. A maximum deflection of 1/8 inch was measured during the traffic test at 0 coverages and was recorded adjacent to the tire using a 4-foot straightedge. This measurement coincides very closely with the analytical prediction (Figure 4). The complete profile was not measurable, since deflections were of such a small order of magnitude. Similar deflection (1/8 inch) was measured at 50, 80, 100, and 150 coverages (Figure 19).

Elevations were recorded at intervals of 0, 50, 80, 100, and 150 F-4 traffic coverages for stations marked on the FRP membrane. Profiles of four lines along the FRP surface (Figure 12) were plotted from the elevation data and are presented in Figures 20 through 23. From these figures, it is evident that the base course densification occurred originally within the first 50 coverages. After reworking of the base course (after 80 coverages), the majority of additional densification under the load cart traffic occurred in the 20 coverages between the 80- and 100-coverage data recording intervals (Figures 22 and 23). The application of 20 coverages of the C-141 load cart produced only very slight additional compaction of the base course (Figures 24 and 25). It is noted that only the crushed limestone deformed (compacted) during trafficking by the load carts. Although the FRP membrane conformed to the base course surface, dishing (permanent deformation of the FRP) did not occur. The FRP membrane performed elastically throughout trafficking.

MEMBRANE COST

The FRP membrane would be employed in place of AM2 matting as a cover to prevent foreign object damage to aircraft. As an additional feasibility factor, the cost of these two alternative covers was compared. Both material and military labor costs were included in deriving the cost of an FRP membrane.

The labor cost for a military crew (Table 4) for membrane fabrication was established as \$85.80/hr (Table 5). Membrane production rate was estimated as 714 ft^2/hr using the AMSS equipment and estimating equipment and crew efficiency at 50%. Thus, the 1980 labor cost for producing the membrane would be approximately \$0.11/ft^2. The 1980 material cost for the FRP membrane is estimated as \$4.24/ft^2.* The total (labor plus material) cost of a membrane would be on the order of \$4.35/ft^2. This represents a savings of 64% over AM2 matting, which has an estimated 1980 price of \$12.00/ft^2 for electron beam welded, MOD 4 AM2 matting.**

The fastening system cost for both covers would be similar and was not considered. Each system would require the same quantity of base course material (to meet NATO specifications for an AM2 surfaced crater

*The following manufacturers were contacted: PPG Industries, Coating and Resin Division, Springdale, Pa. and Fiberglass Industries, Hexcell-Traverno Division, Amsterdam, N.Y.

**Fonecon, Jan 1980 with Ms. D. Braun, AM2 Product Manager, Martin-Marietta Corp.

repair), and each would offer extremely long shelf life. The cost savings is attributed to the simpler fabrication procedure utilized for membrane construction and the high production rate of AMSS equipment. AM2 cost is elevated by energy intensive and expensive fabrication processes involving alloying and tempering of the aluminum, extrusion of planks in a 24-in.-width (few available manufacturers), and the welding of end connectors.

Additional, less quantifiable benefits which would be derived from adoption of the FRP membrane concept of RRR include:

- Cycling of stockpiled polyester resin (pre-positioned war reserve stocks for the AMSS) which has a predicted 5-year shelf life. Membrane production would be a valid and valuable product for the aging polyester resin, thereby increasing its salvage value.
- Field training of Marine Corps personnel during peacetime to provide a high state of readiness and mobility for the employment of the AMSS in an amphibious objective area during war. The value of this training might be considered as offsetting the military labor cost associated with membrane fabrication.

CONCLUSIONS AND RECOMMENDATIONS

The traffic tests conducted at the Rapid Runway Repair Test Facility of the AFESC have demonstrated the endurance of an FRP membrane to repeated F-4 and C-141 traffic when placed over a 24-in.-thick, compacted, crushed limestone base course overlying a low-strength clay subgrade. The FRP membrane proved to be removable and gave excellent performance without experiencing any failure or noticeable wear from the applied traffic or handling. In summary, RRR using FRP membranes and crushed stone is feasible and offers savings in construction of the cap of 64% over similar repair concepts using AM2 matting.

The following recommendations are presented for further research which is required to complete development of the FRP membrane concept of RRR:

1. Conduct a field test with a C-141 load cart to determine the adequacy of the FRP membrane and tie-down bolts for resisting braking and deceleration forces which would be produced by a C-141.

2. Conduct further analytical study in conjunction with field load cart traffic testing to determine whether base course thickness can be decreased, possibly through the use of a filter fabric at the base course-debris interface.*

3. Undertake field fabrication of membranes using the AMSS equipment to determine the largest size of membrane that would be feasible for field fabrication and handling.

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*Hauling and placement of the base course is on the critical path (thus determining completion time) for the repair of a crater. Reduction of base course thickness would shorten repair time or reduce equipment requirements.

4. Investigate bonding and joining methods for the production of large membranes from several smaller segments if single-piece membranes of sufficient size cannot be field-produced for the repair of a 750-lb bomb crater.

5. Traffic test the completed concept under actual F-4 and C-141 operations.

ACKNOWLEDGMENTS

The valuable assistance and dedication of Mr. Leonard Woloszynski and Mr. Larry Underbakke, civil engineering technicians at CEL, in the preparation of the FRP membrane and installation of instrumentation is gratefully acknowledged. Appreciation is also expressed to the Air Force Engineering and Services Center for the use of the Rapid Runway Repair Test Facility, preparation and testing of the clay subgrade and crushed stone base course, and surveying and trafficking of the FRP membrane.

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Table 1. Physical Properties of Wewahitchka Clay (Ref 8)

Properties	Range	Average
Liquid Limit	57 - 79	65
Plastic Limit	21 - 30	25
Plasticity Index	30 - 52	41
Specific Gravity	2.58 - 2.67	2.61
CE-55 Opt Dry Density, pcf	110 - 115	113
Opt Moisture, %	13 - 15	14.5
CE-26 Opt Dry Density, pcf	105 - 109	107
Opt Moisture, %	13 - 16.5	14.5
CE-12 Opt Dry Density, pcf	98 - 102.5	99.0
Opt Moisture, %	11.5 - 18	15.0

Table 2. Mineralogical Composition of Wewahitchka Clay

Mineral Constituents	Relative Sample Contents
Clay	
Kaolinite	Intermediate (25%-50%)
Smectite	Common (10%-25%)
Clay-mica	Common (10%-25%)
Non-clays	
Quartz	Intermediate (25%-50%)
Feldspars	Rare (>5%)

Table 3. Soil Data for Clay Subgrade and Crushed Stone Base Course

Test No.	Depth[a] (in.)	Wet Density[b] (pcf)	Dry Density (pcf)	Moisture Content[b] (%)	CBR[c] (%)
Clay					
1	24	118.9	90.3	31.7	4.8
	28	122.8	93.8	30.9	
	32	123.4	94.5	30.6	
	36	124.2	95.5	30.0	
Crushed Stone					
2	4	148.8	144.5	3.0	d
	8	149.2	145.0	2.9	
	12	147.3	143.0	3.0	
Crushed Stone					
3	4	148.8	143.4	3.8	d
	8	148.5	143.2	3.7	
	12	147.5	142.1	3.8	

[a]Depth measured from surface of adjacent concrete.

[b]Average of two readings.

[c]Average of six tests.

[d]Not measured.

Table 4. Typical AMSS Crew for FRP Membrane Fabrication

Pay Grade	No. of Persons	Function
01	1	OIC - overall project coordination
E6	1	Jobsite supervisor
E5	1	Low-rate unit operator
E4	1	Crew leader - material resupply
E4	1	Spray-gun operator
E4	1	RT forklift operator
E3	2	Fiberglass handlers
E3	2	Hose handlers
E3	4	Fiberglass rolling crew
E4	1	Expediter
Total	15	

Table 5. Breakdown of AMSS Crew Labor Cost[a]

Pay Grade	1980 Basic Hourly Rate ($)	1980 Acceleration Factor	Accelerated Hourly Rate ($)
01	6.96	1.545	10.75
E6	6.71	1.695	11.37
E5	5.60	1.695	9.49
E4	4.87	1.695	8.26
E3	4.16	1.695	7.05
Total Crew Labor Cost			85.80

[a]Basic hourly rates and acceleration factors extracted from Reference 14 (NAVCOMPTNOTE 7041).

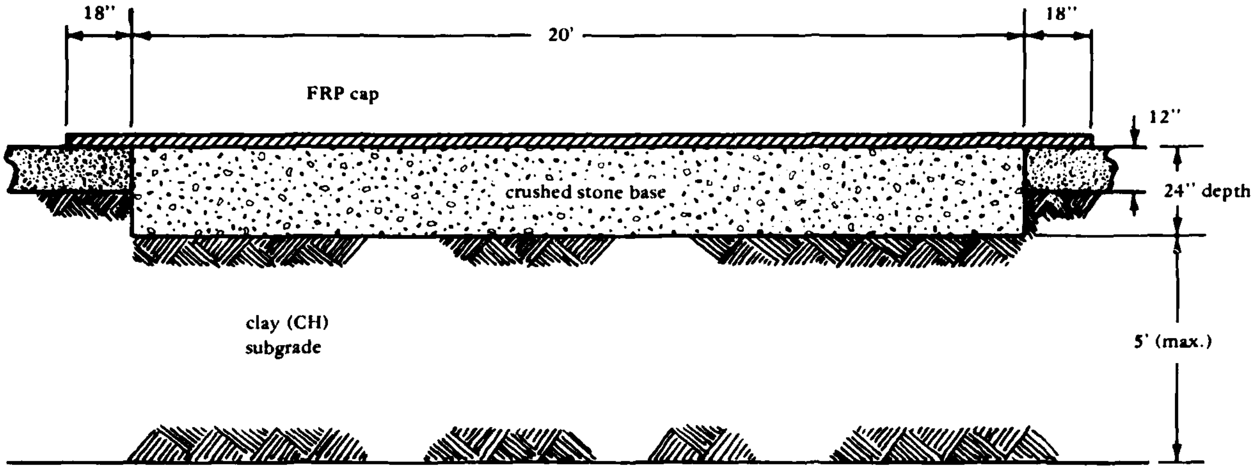

Figure 1. RRR test section profile.

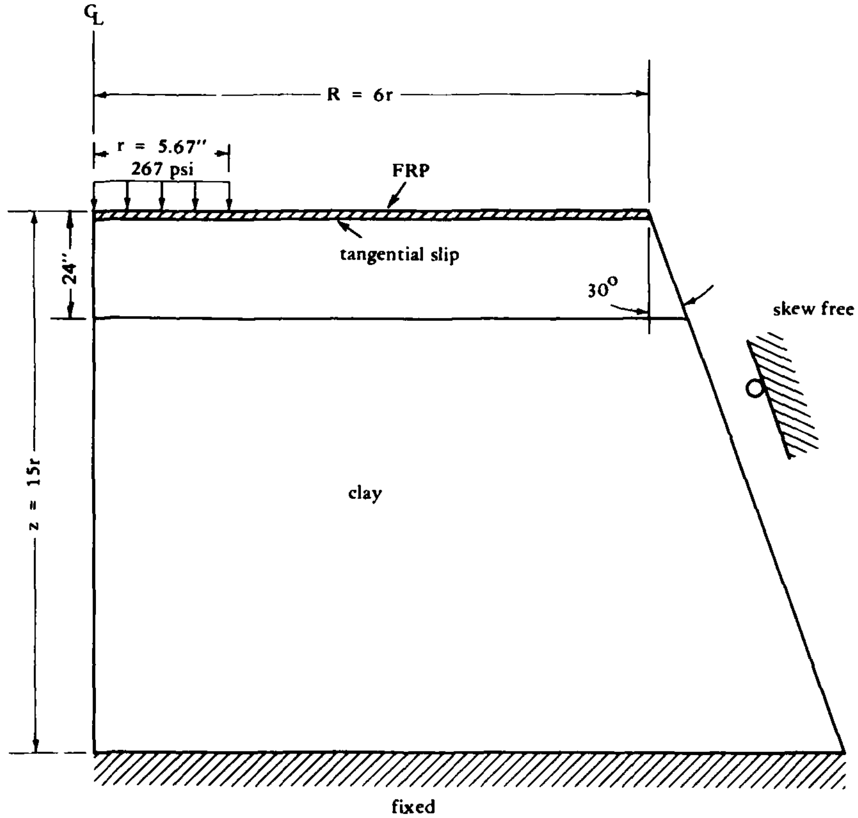

Figure 2. Idealized RRR cross section
with crushed stone base.

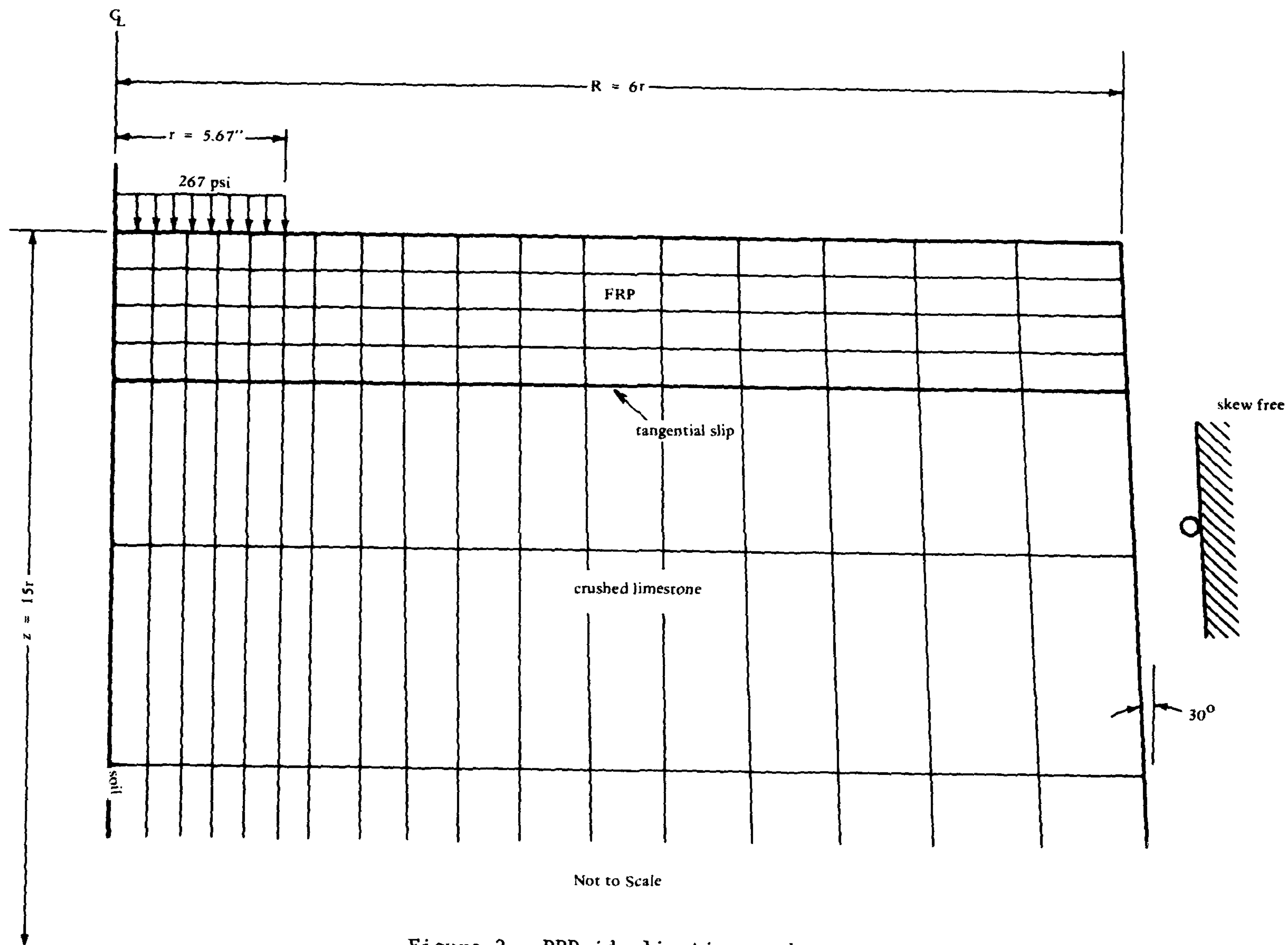

Figure 3. RRR idealization mesh.

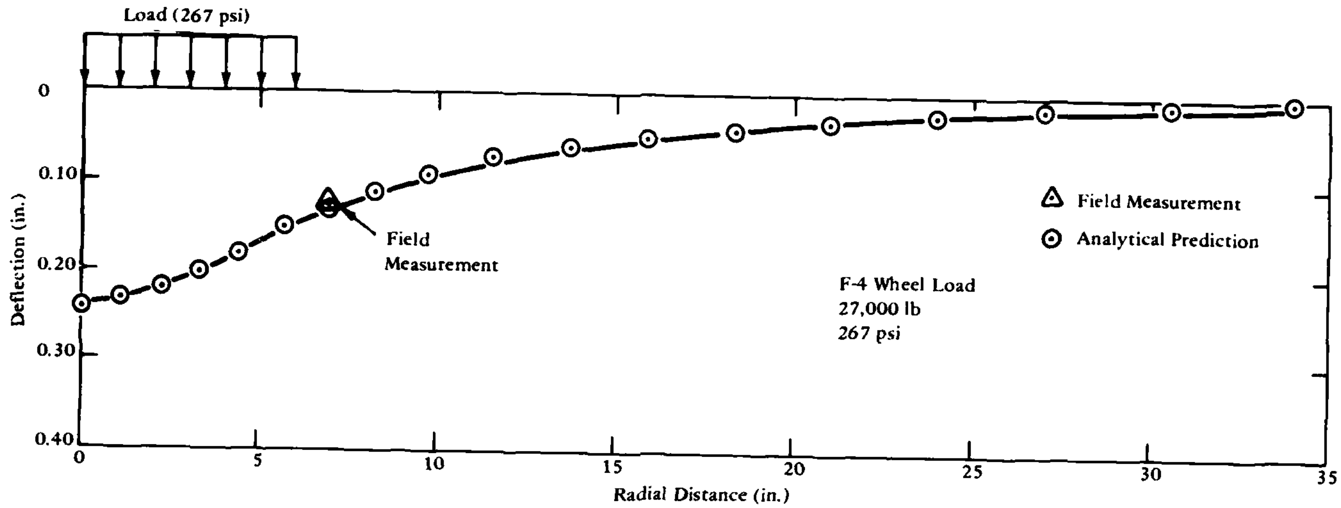

Figure 4. Deflection profile for 1/2-in. FRP over 24-in. crushed stone base.

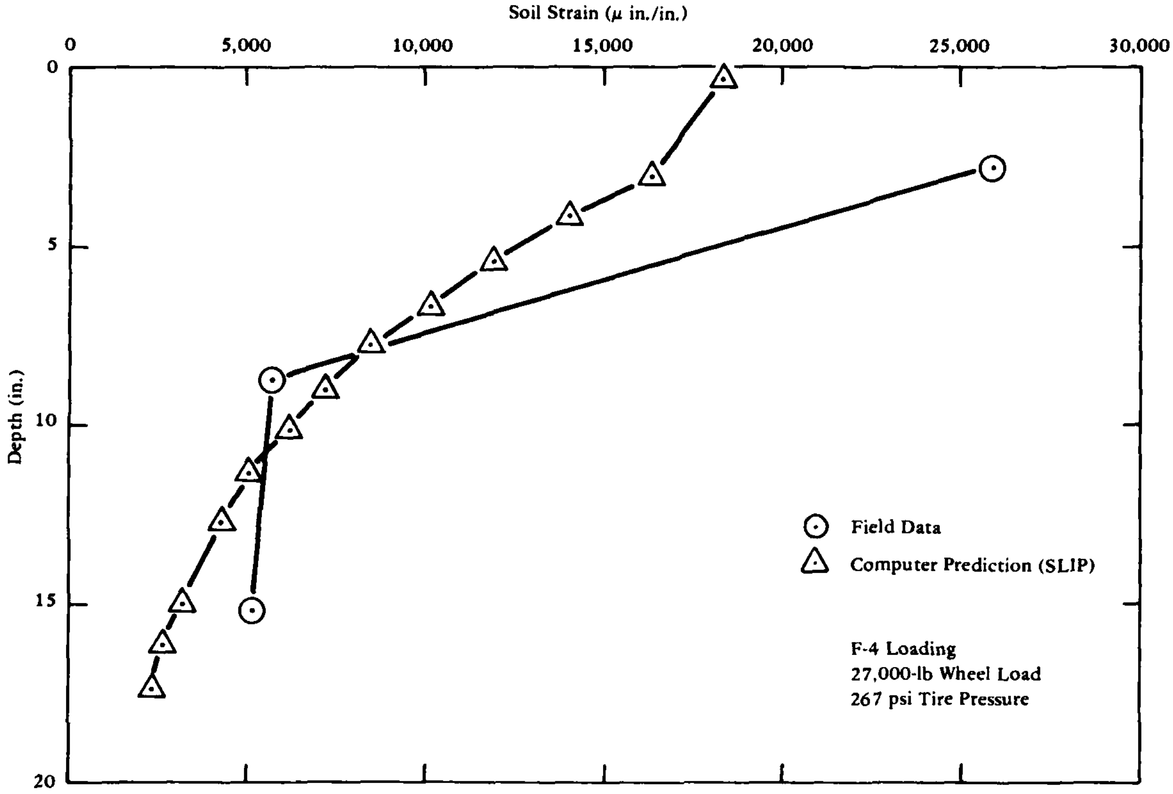

Figure 5. Centerline soil strain.

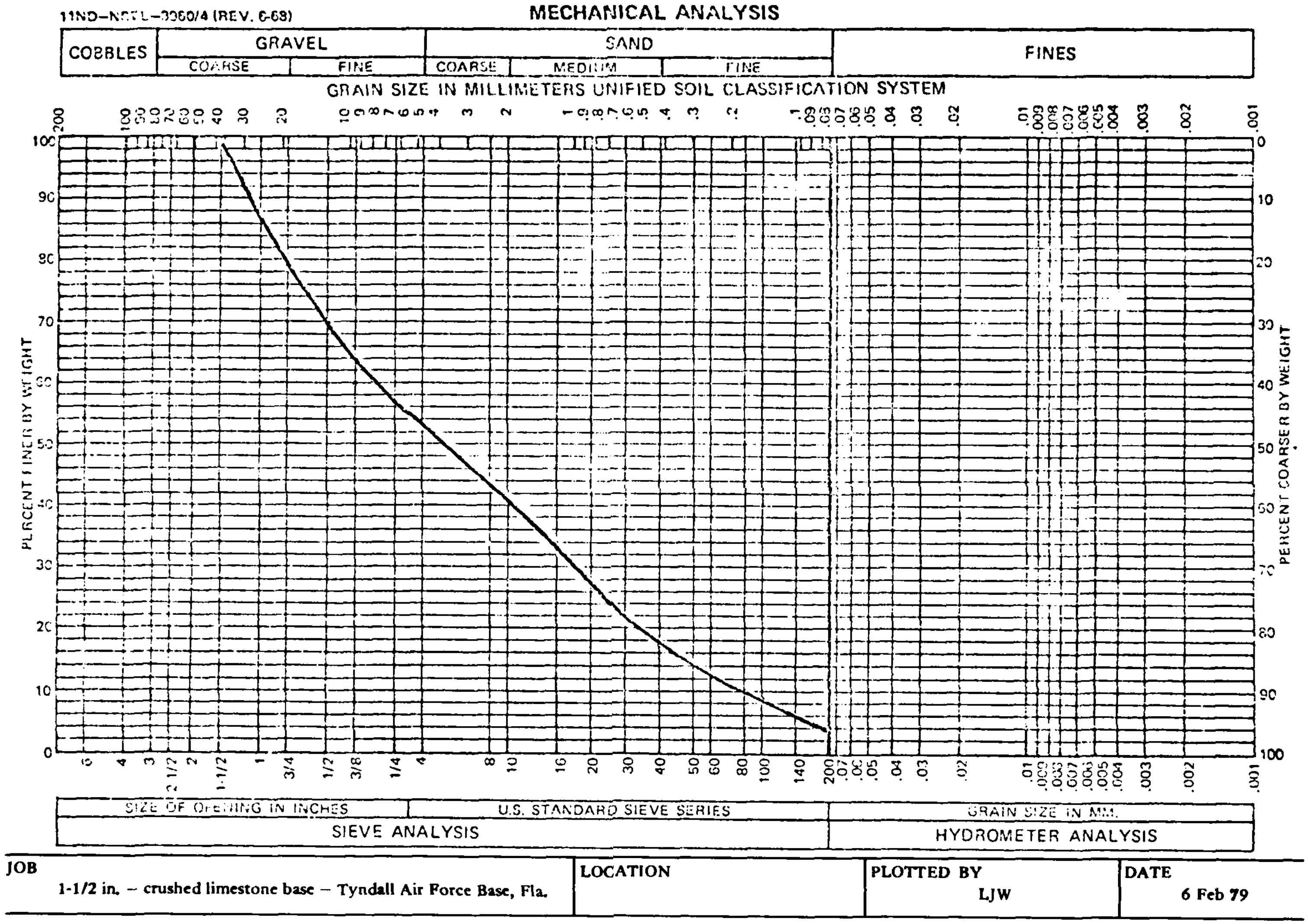

Figure 6. Grain size distribution of Tyndall crushed stone (Ref 6).

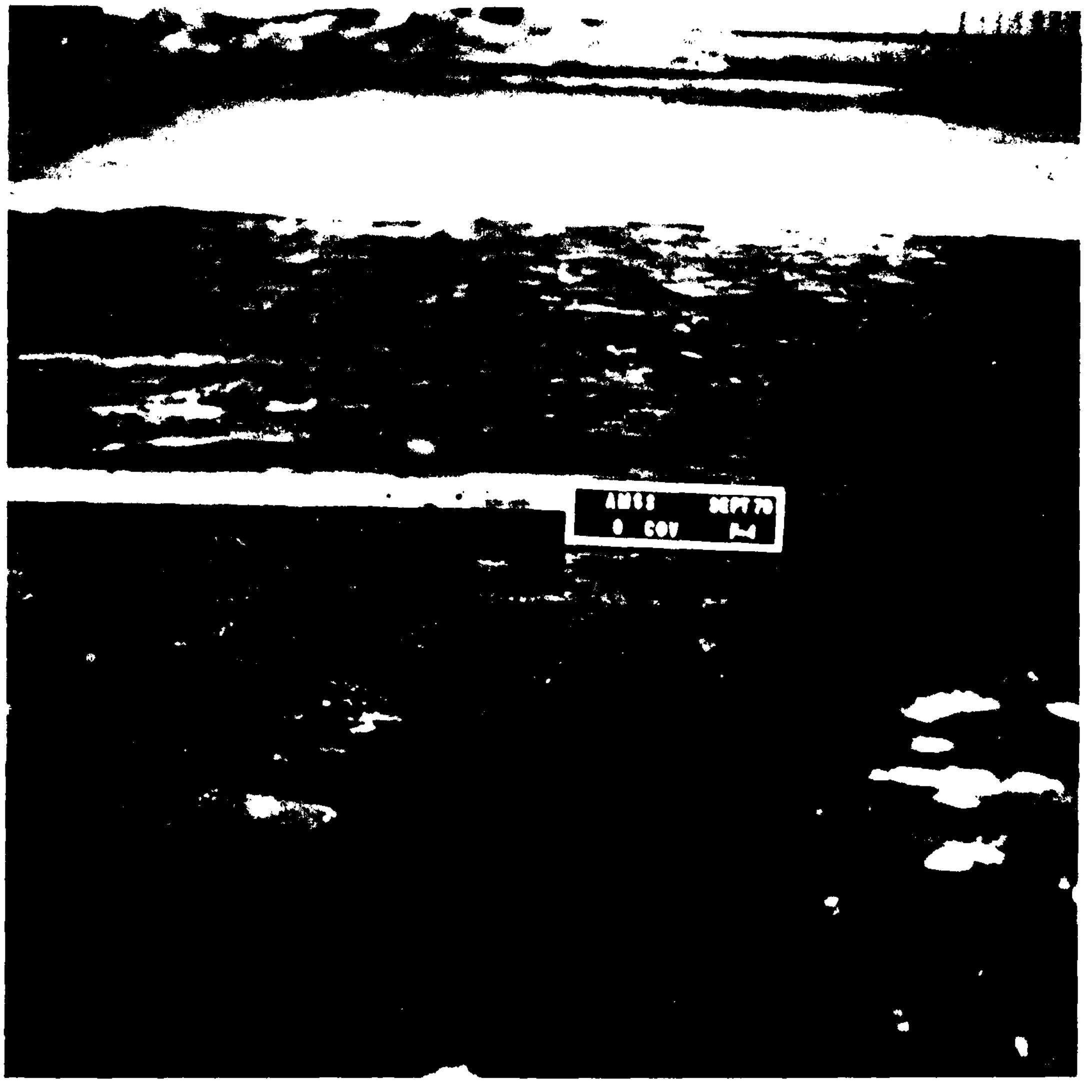

Figure 7. Completed FRP membrane.

Figure 8. Towing completed FRP membrane.

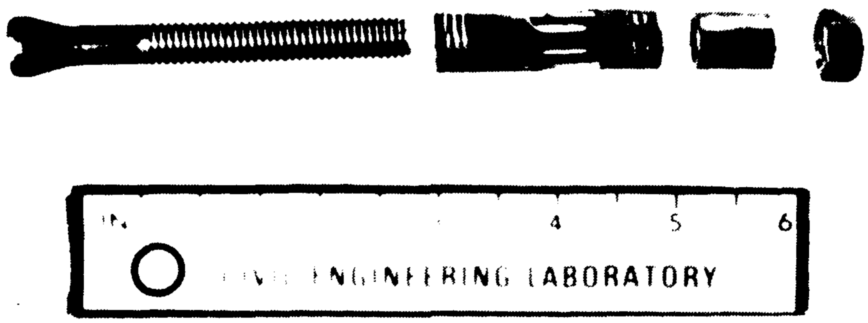

Figure 9. Torque-set fastener, 1/2-in. x 3-in.

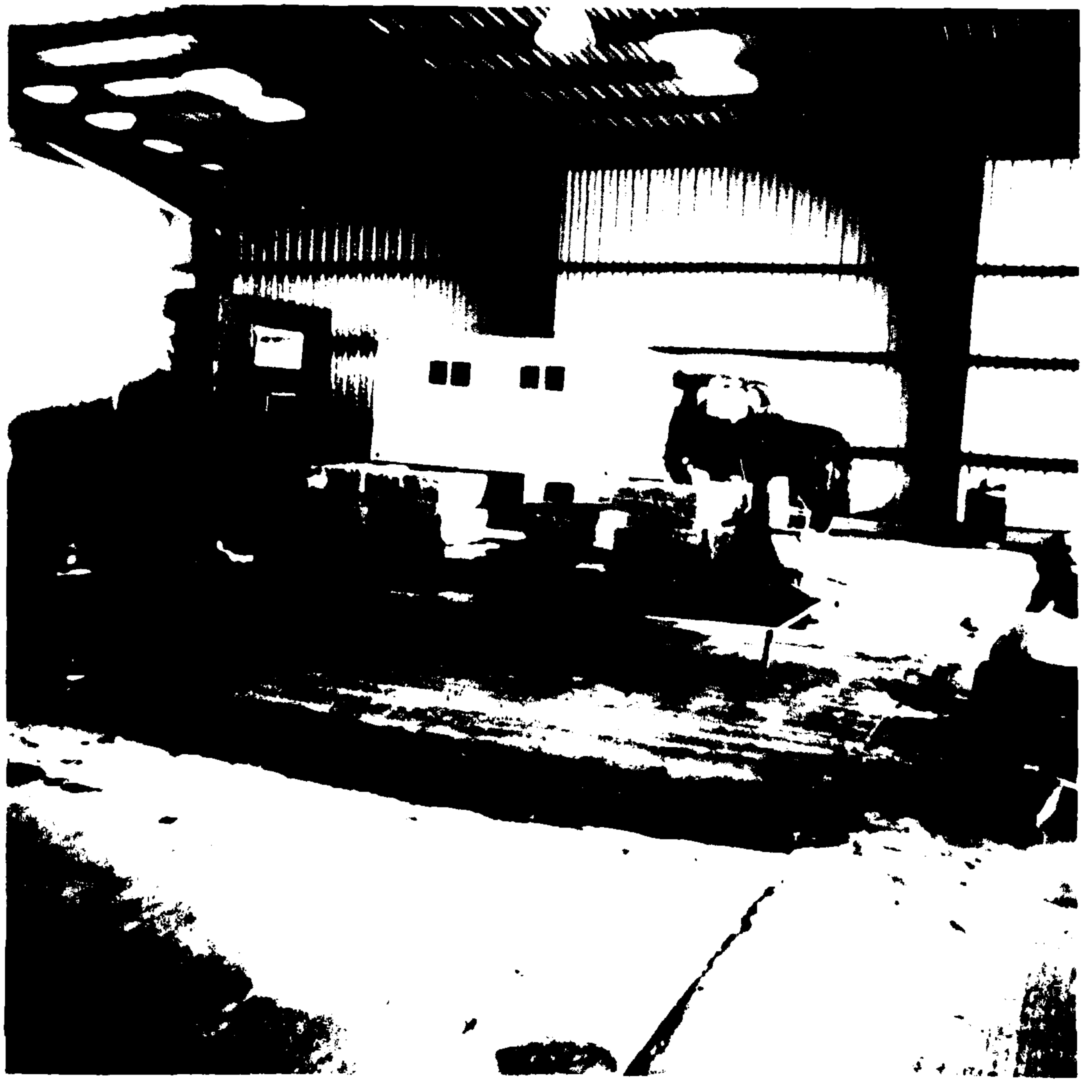

Figure 10. F-4 load cart.

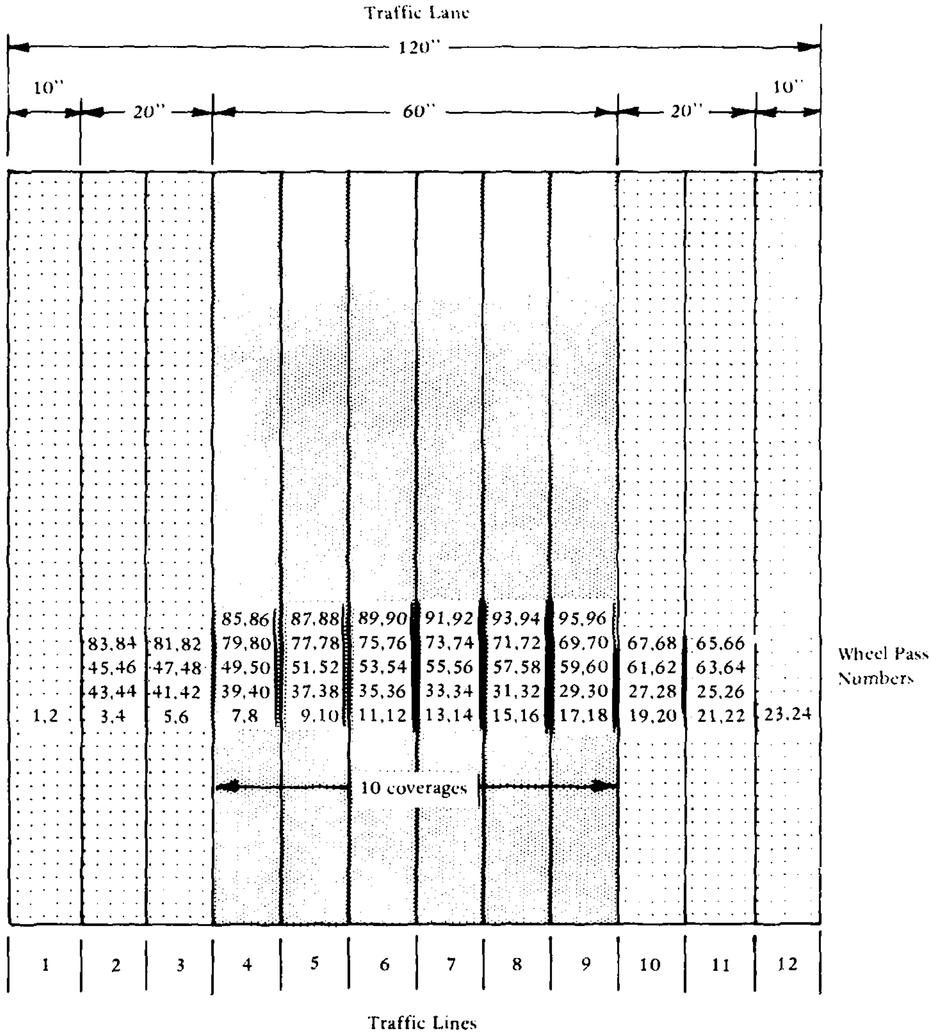

Figure 11. Traffic distribution pattern for the F-4 load cart.

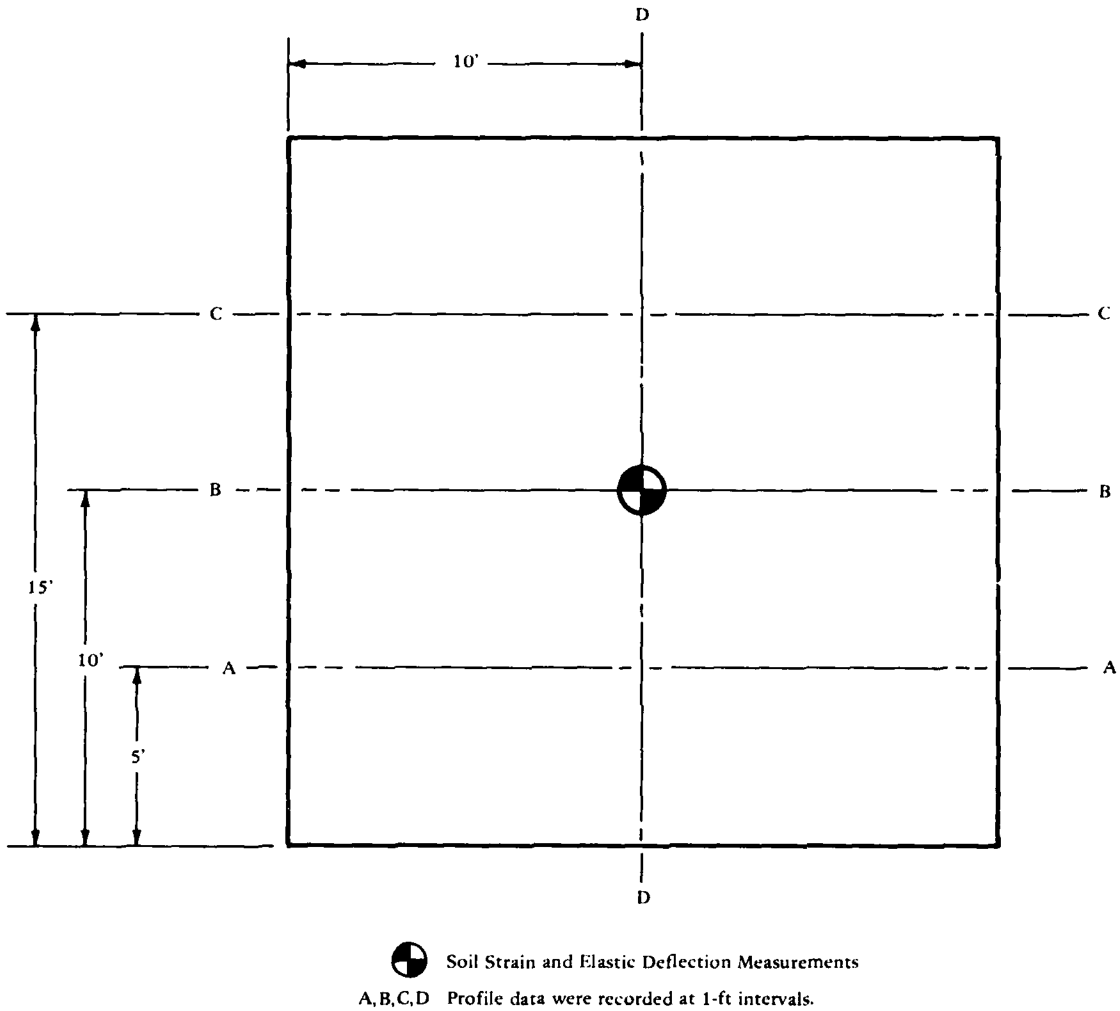

Figure 12. Data collection points.

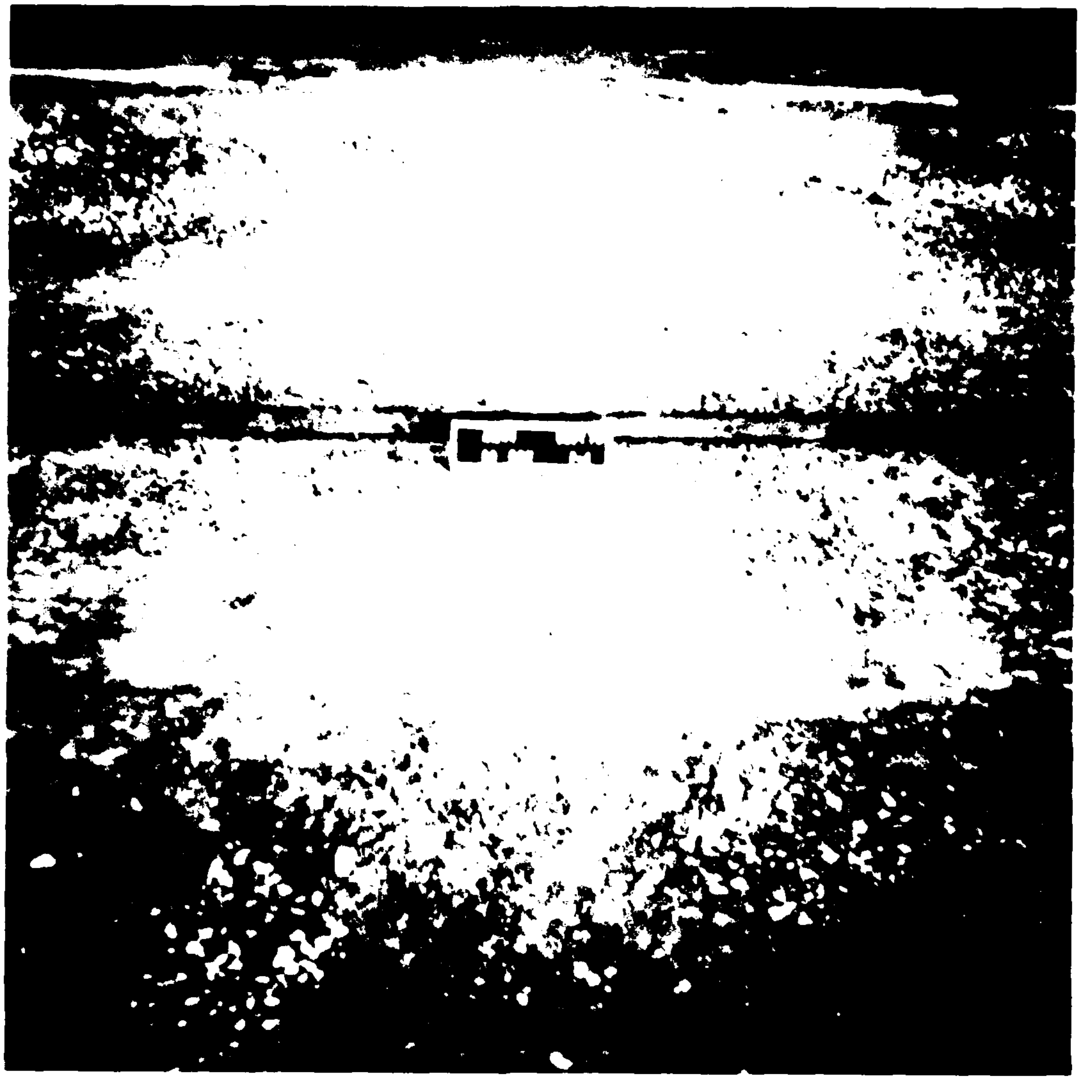

Figure 13. Crushed limestone base course after 80 F-4 coverages.

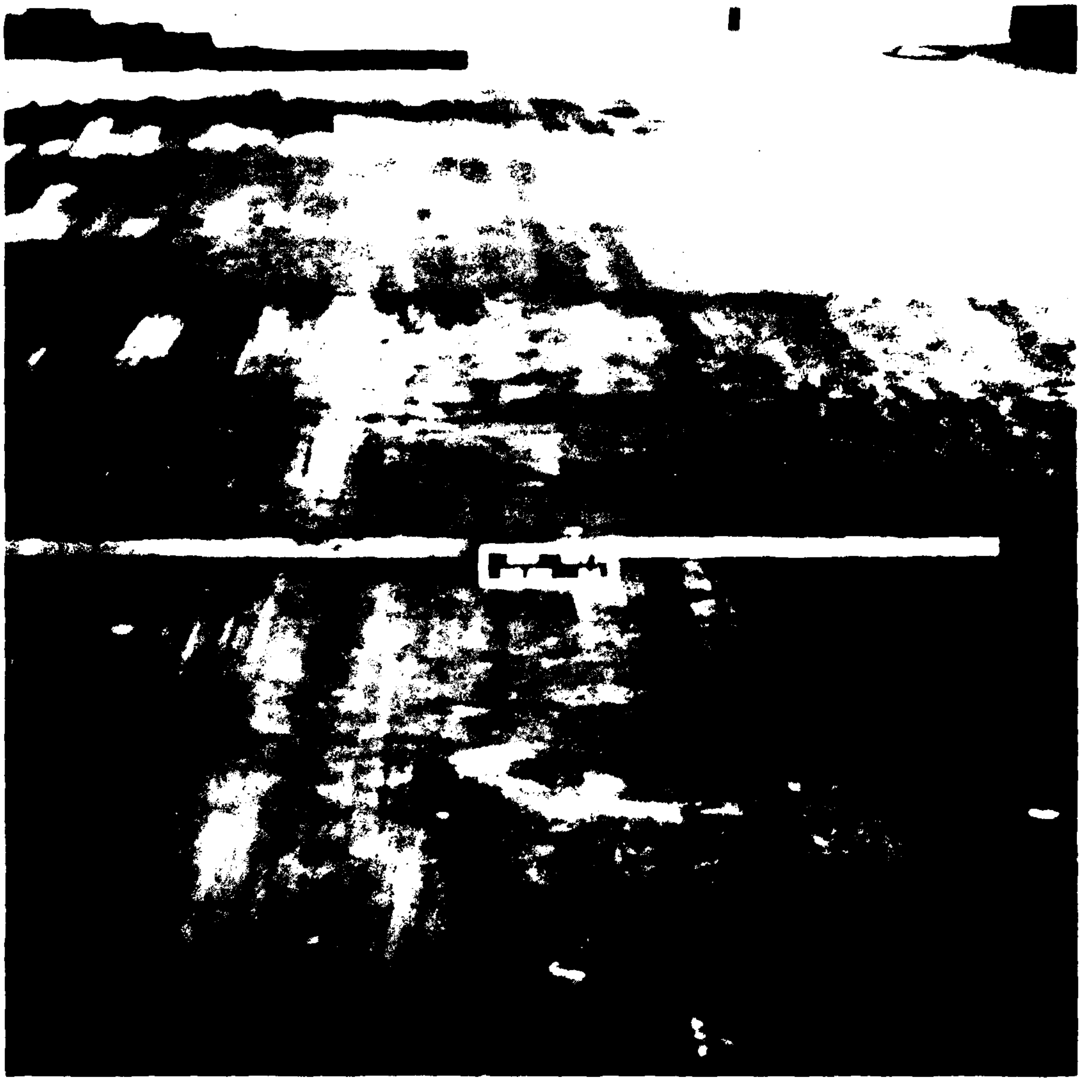

Figure 14. FRP test section after 150 F-4 coverages.

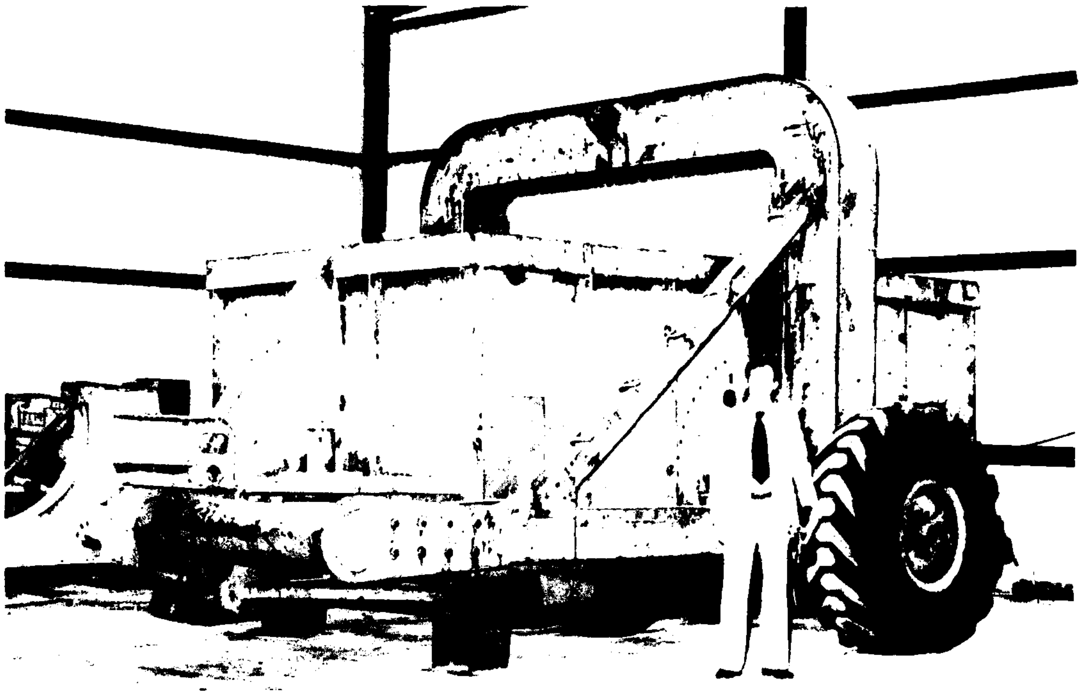

Figure 15. C-141 load cart.

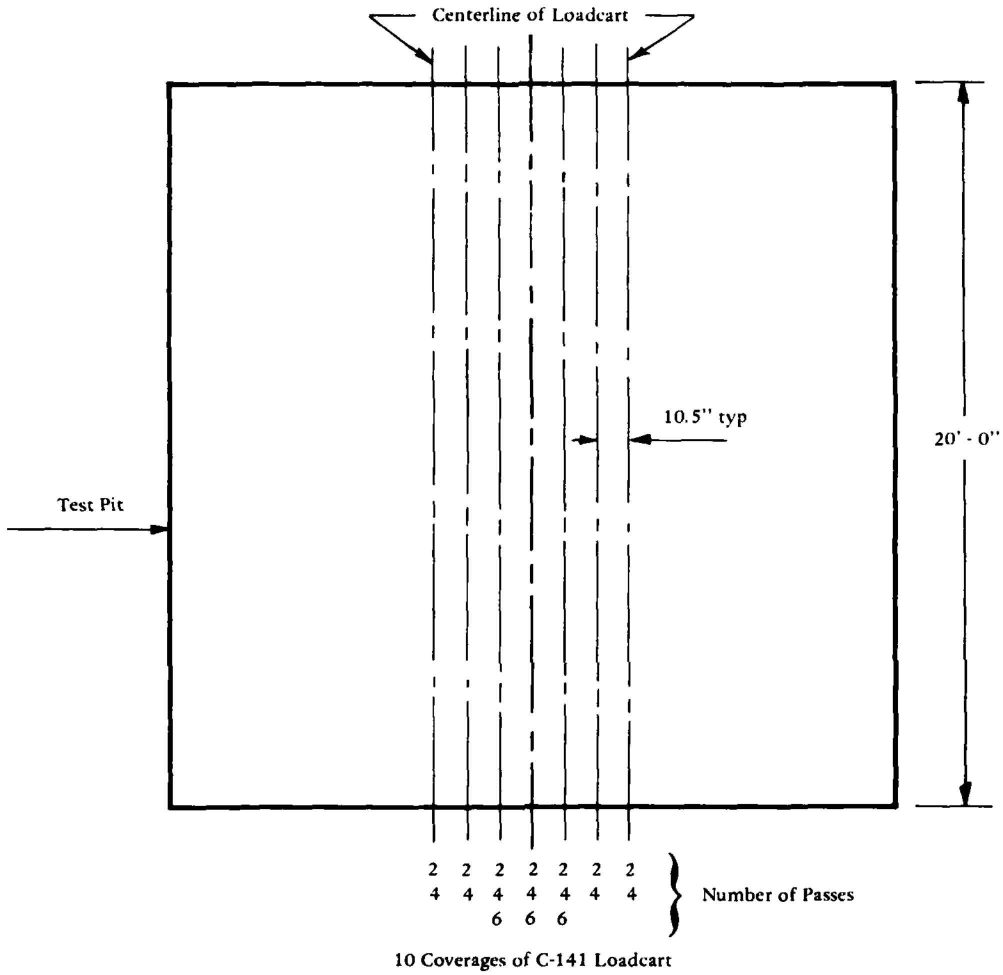

Figure 16. Traffic distribution pattern for the C-141 load cart.

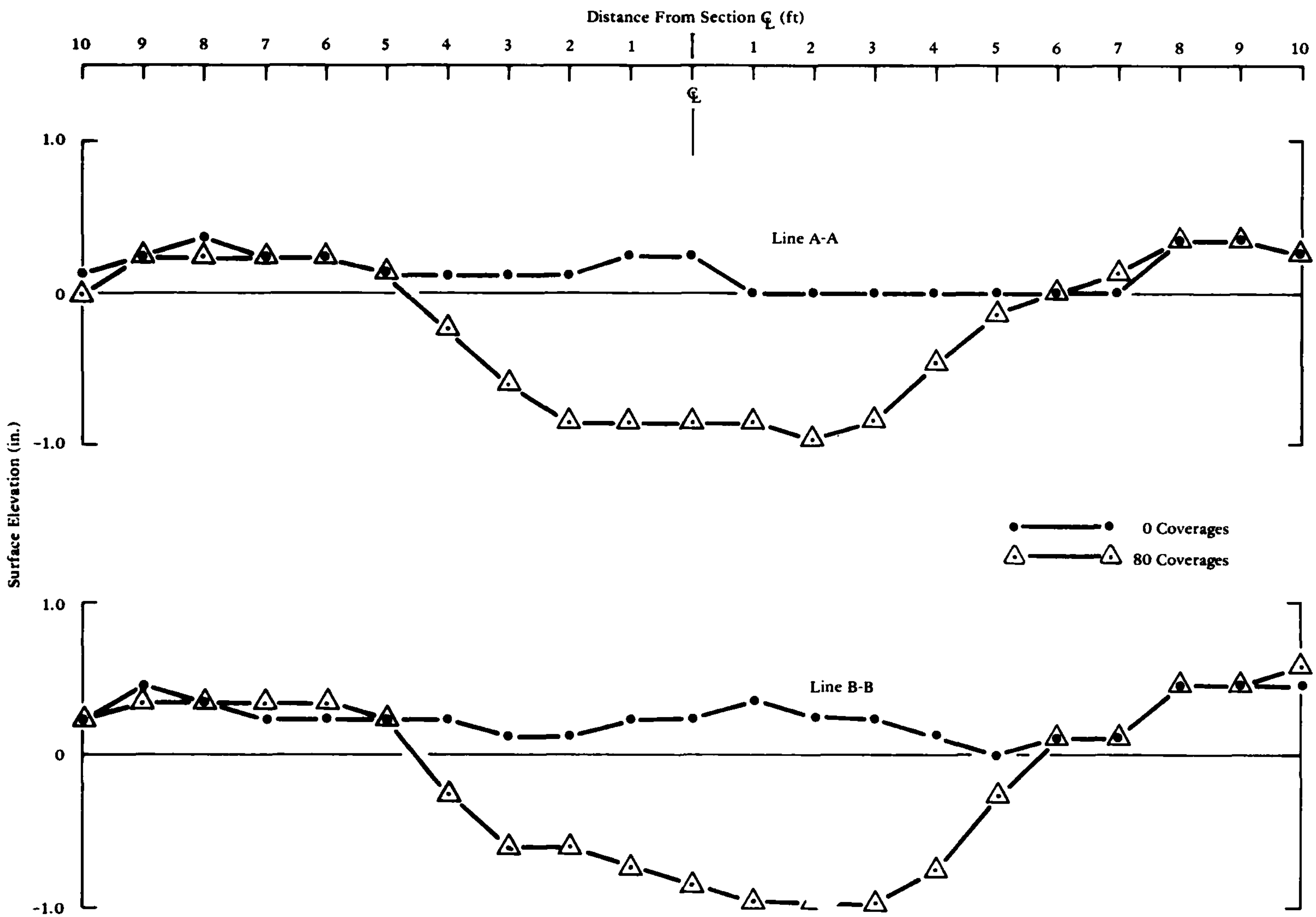

Figure 17. Profiles of base course surface at lines A and B for 0 and 80 F-4 coverages.

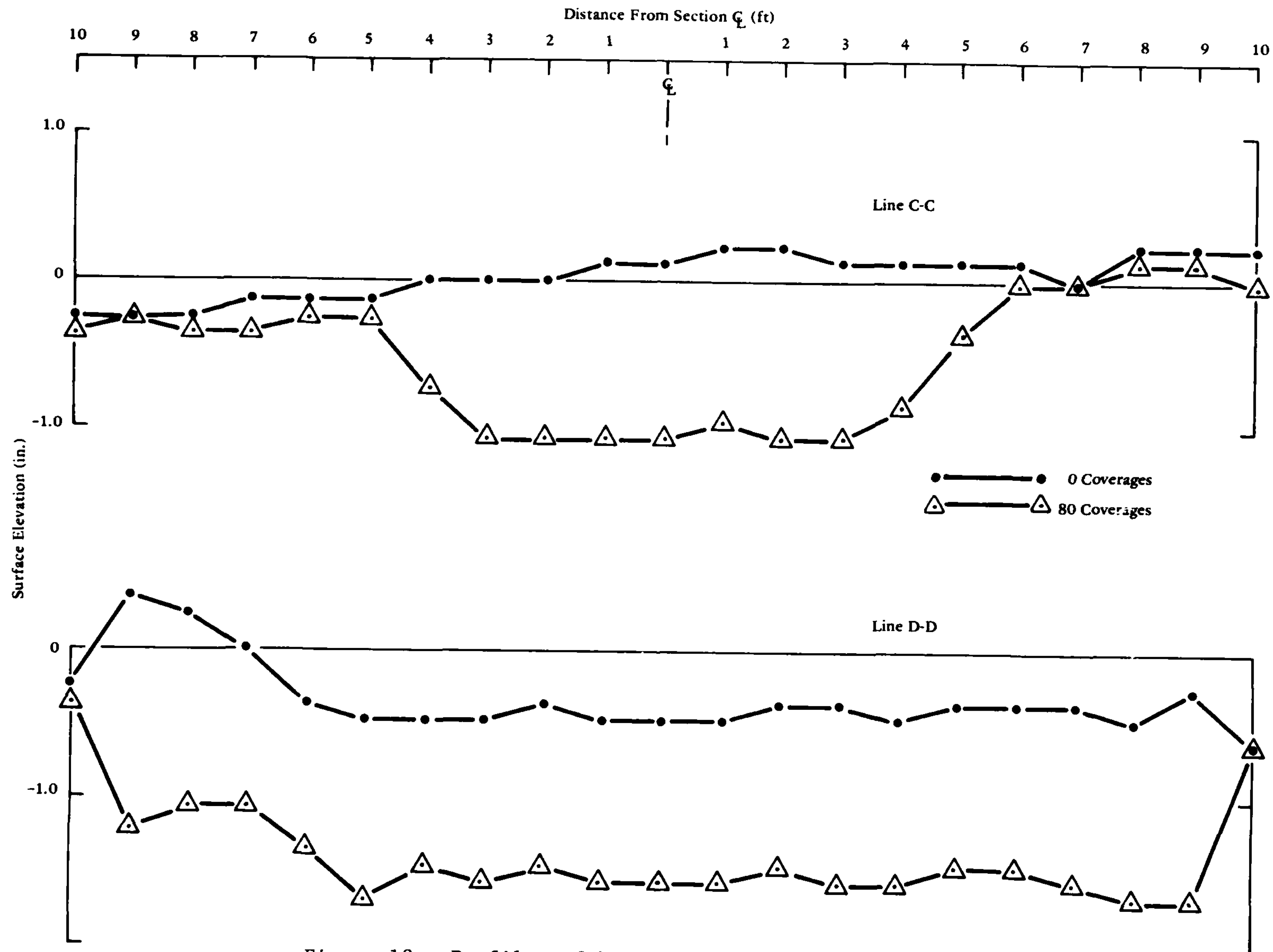

Figure 18. Profiles of base course surface at lines C and D for 0 and 80 F-4 coverages.

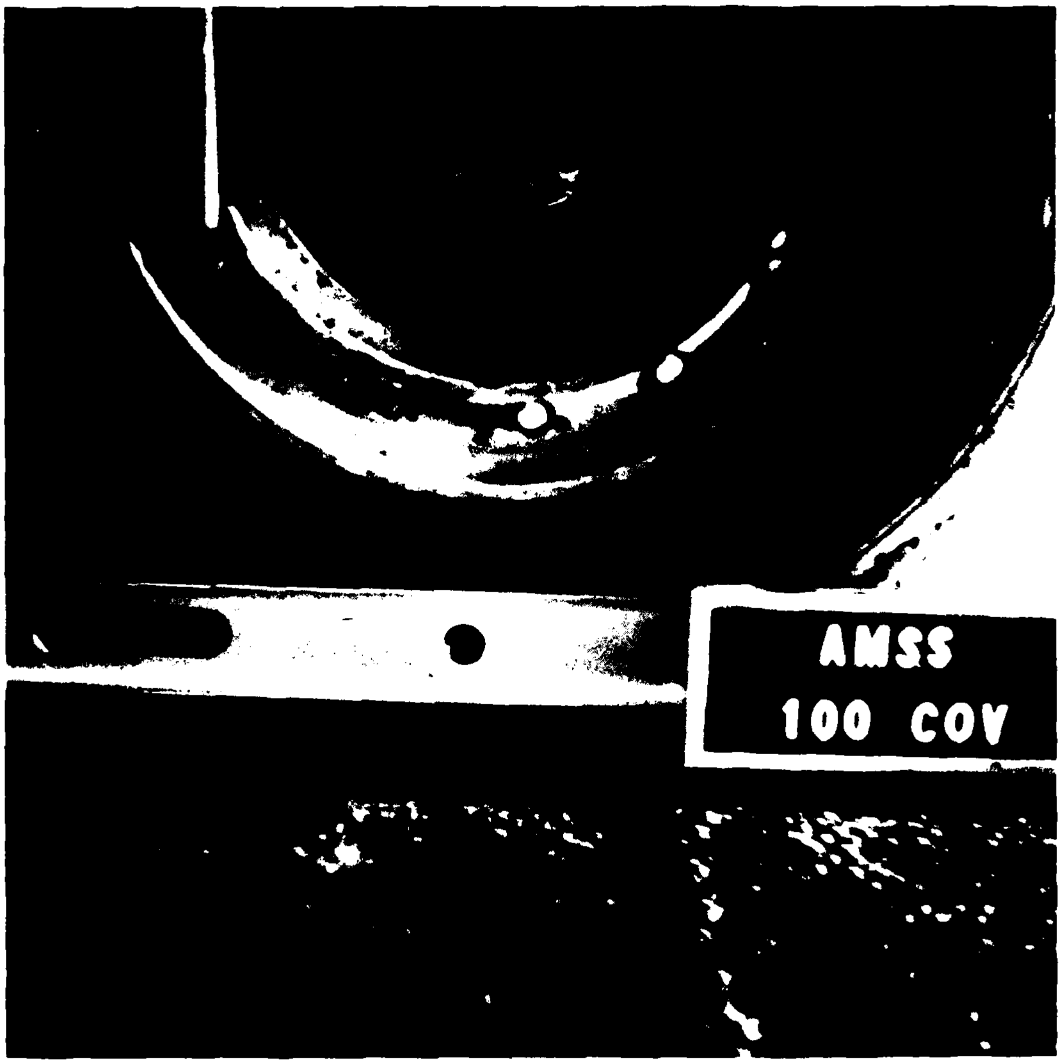

Figure 19. Deflection of FRP membrane for F-4 wheel load at 100 coverages.

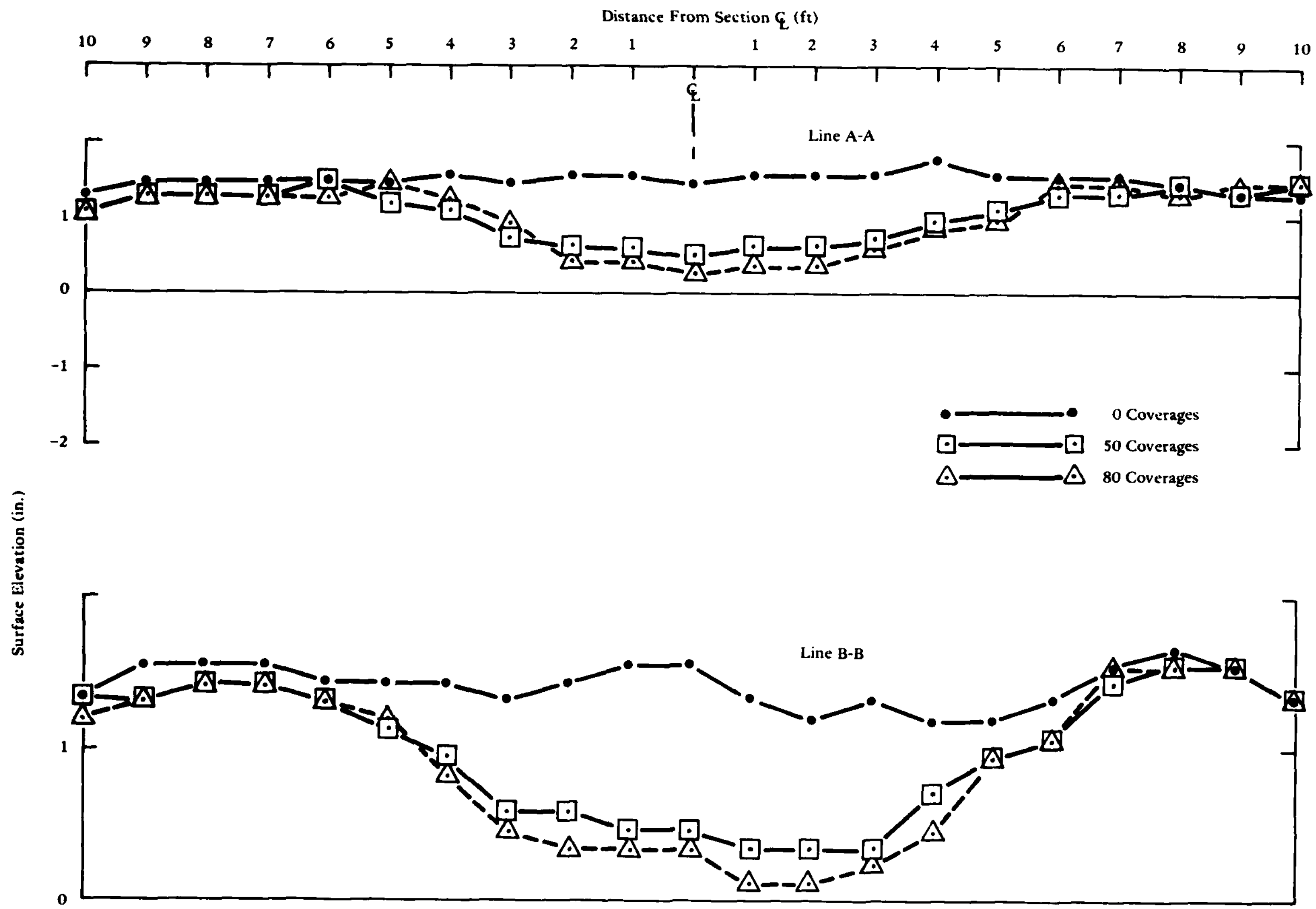

Figure 20. Profiles of FRP surface at lines A and B for 0 to 80 F-4 coverages.

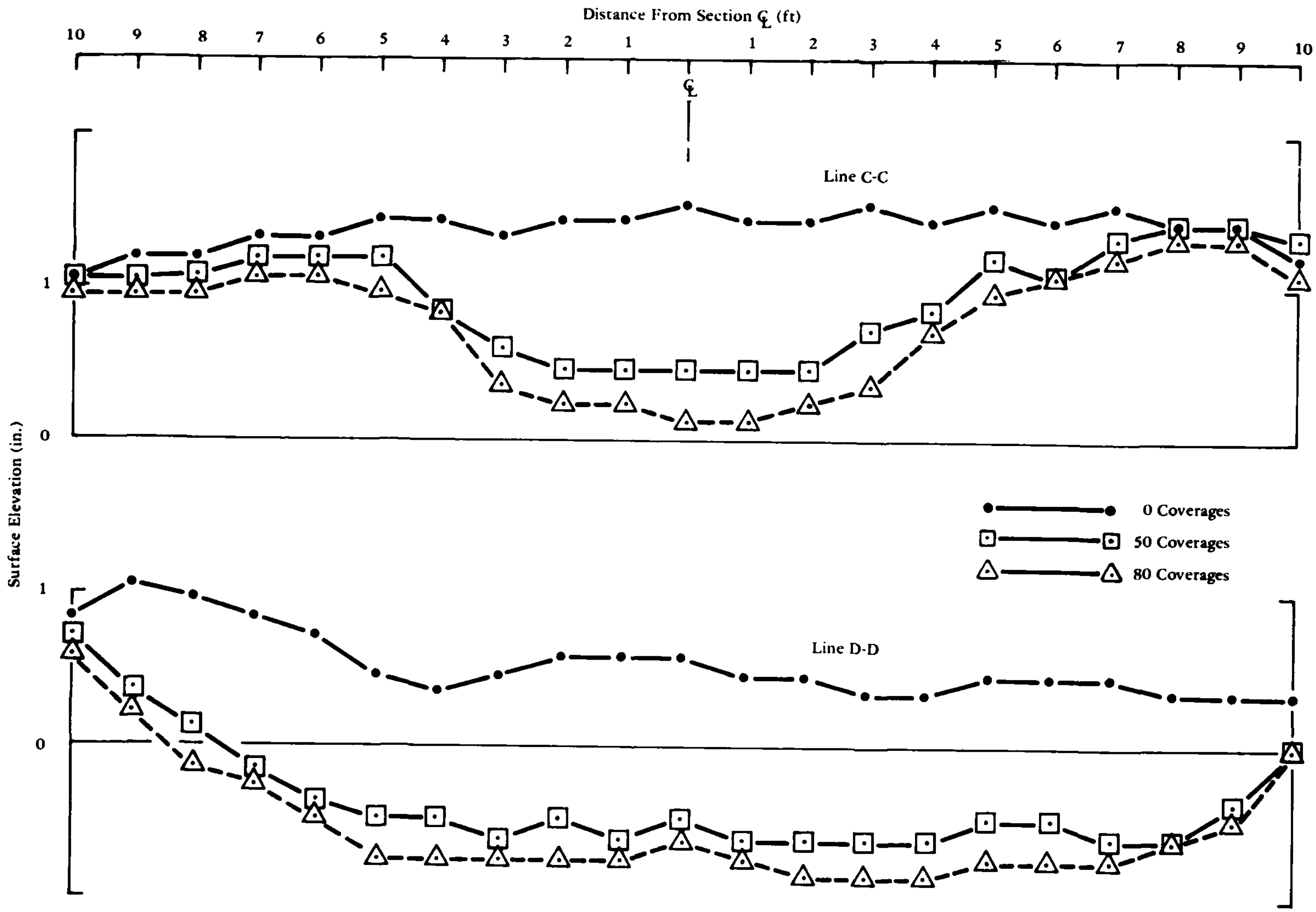

Figure 21. Profiles of FRP surface at lines C and D for 0 to 80 F-4 coverages.

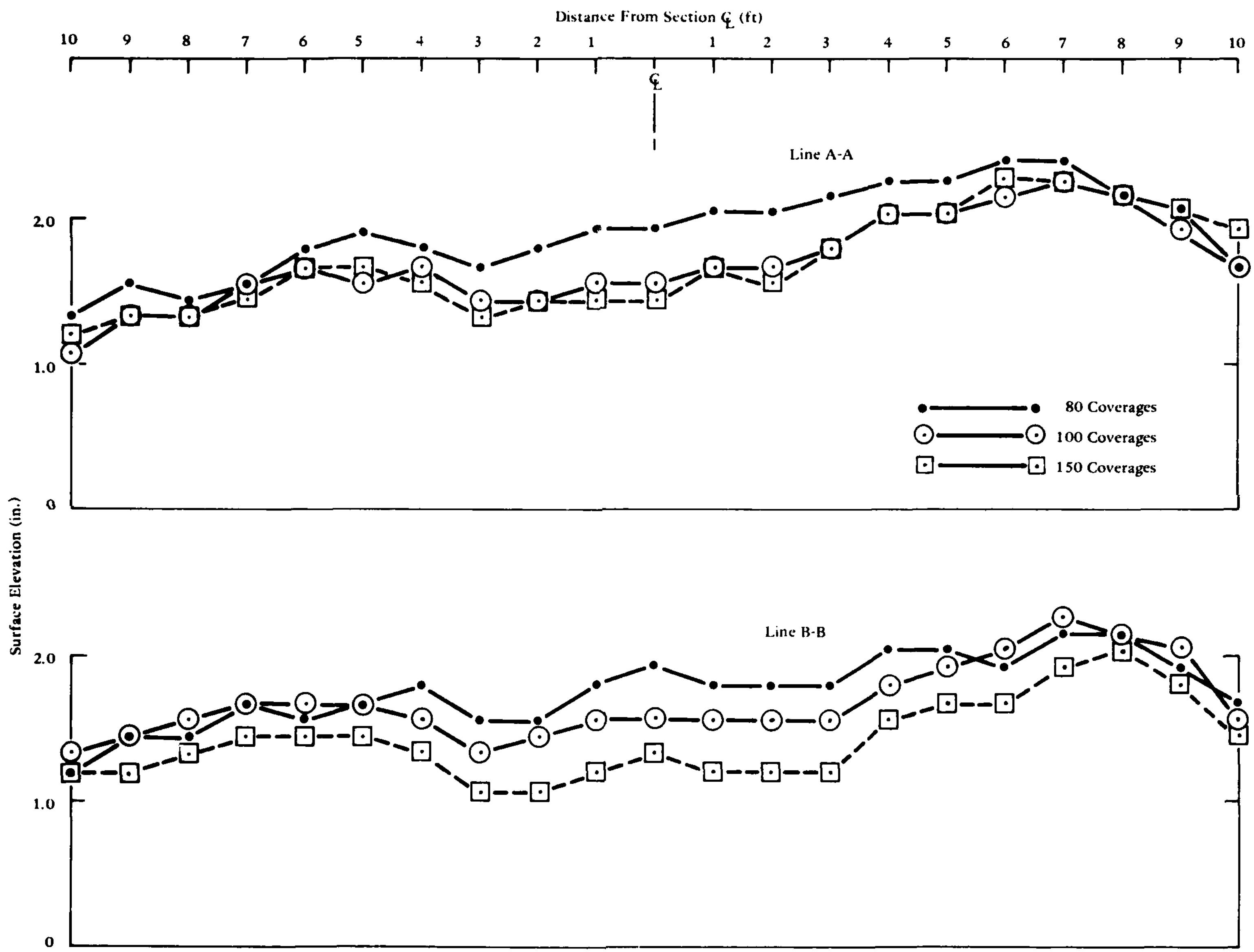

Figure 22. Profiles of FRP surface at lines A and B for 80 to 150 F-4 coverages.

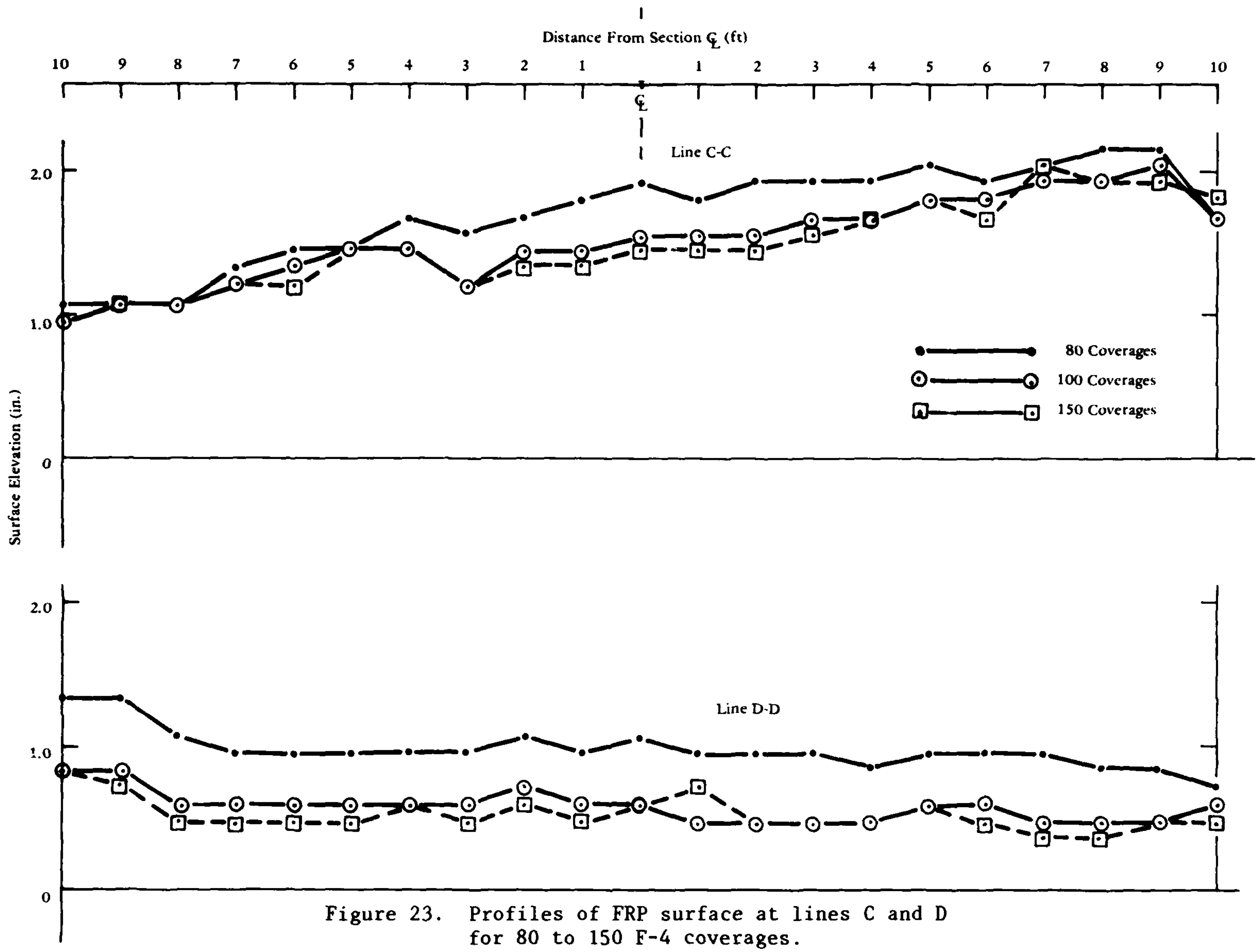

Figure 23. Profiles of FRP surface at lines C and D
for 80 to 150 F-4 coverages.

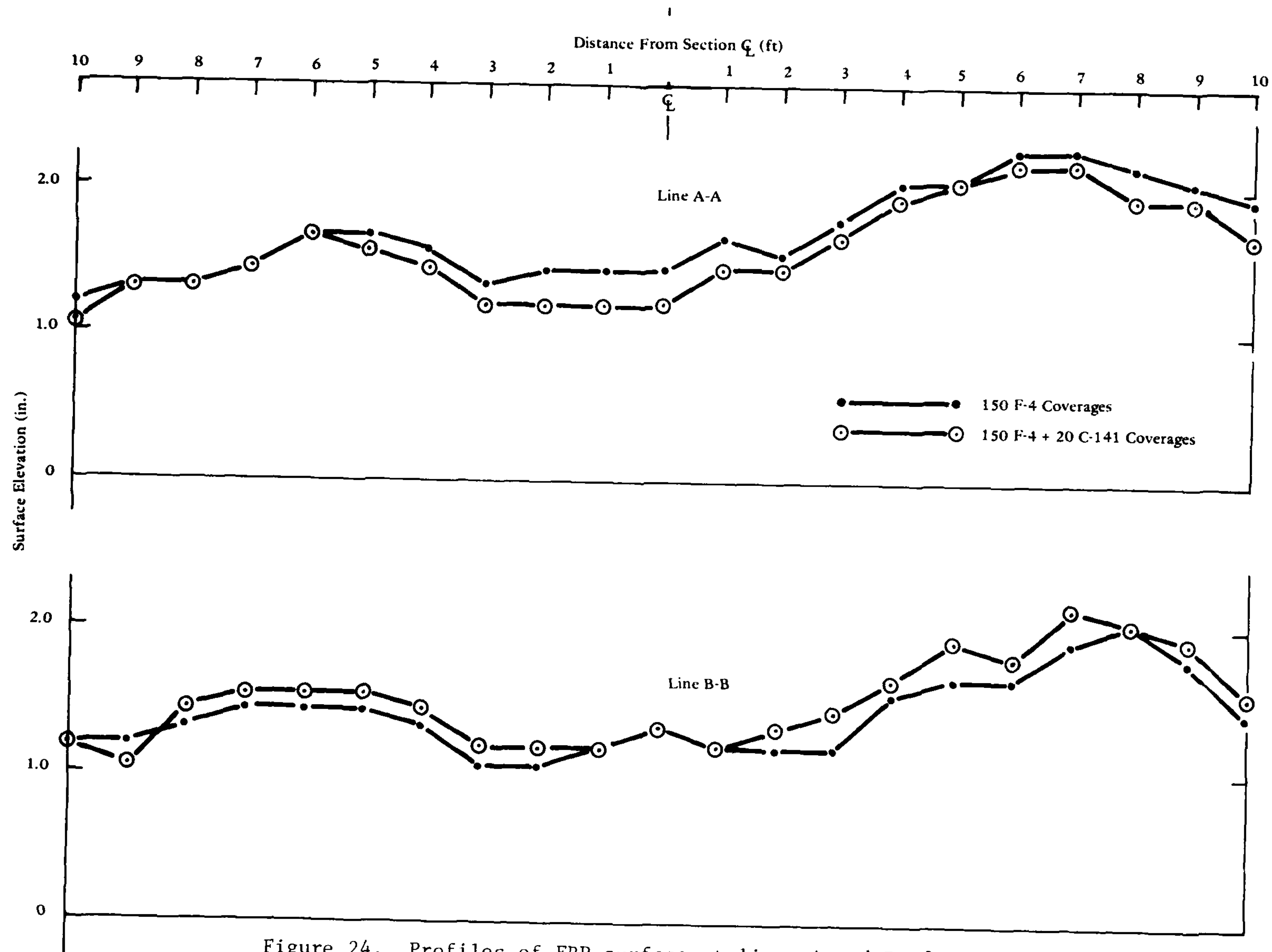

Figure 24. Profiles of FRP surface at lines A and B after 150 F-4 coverages and 20 C-141 coverages.

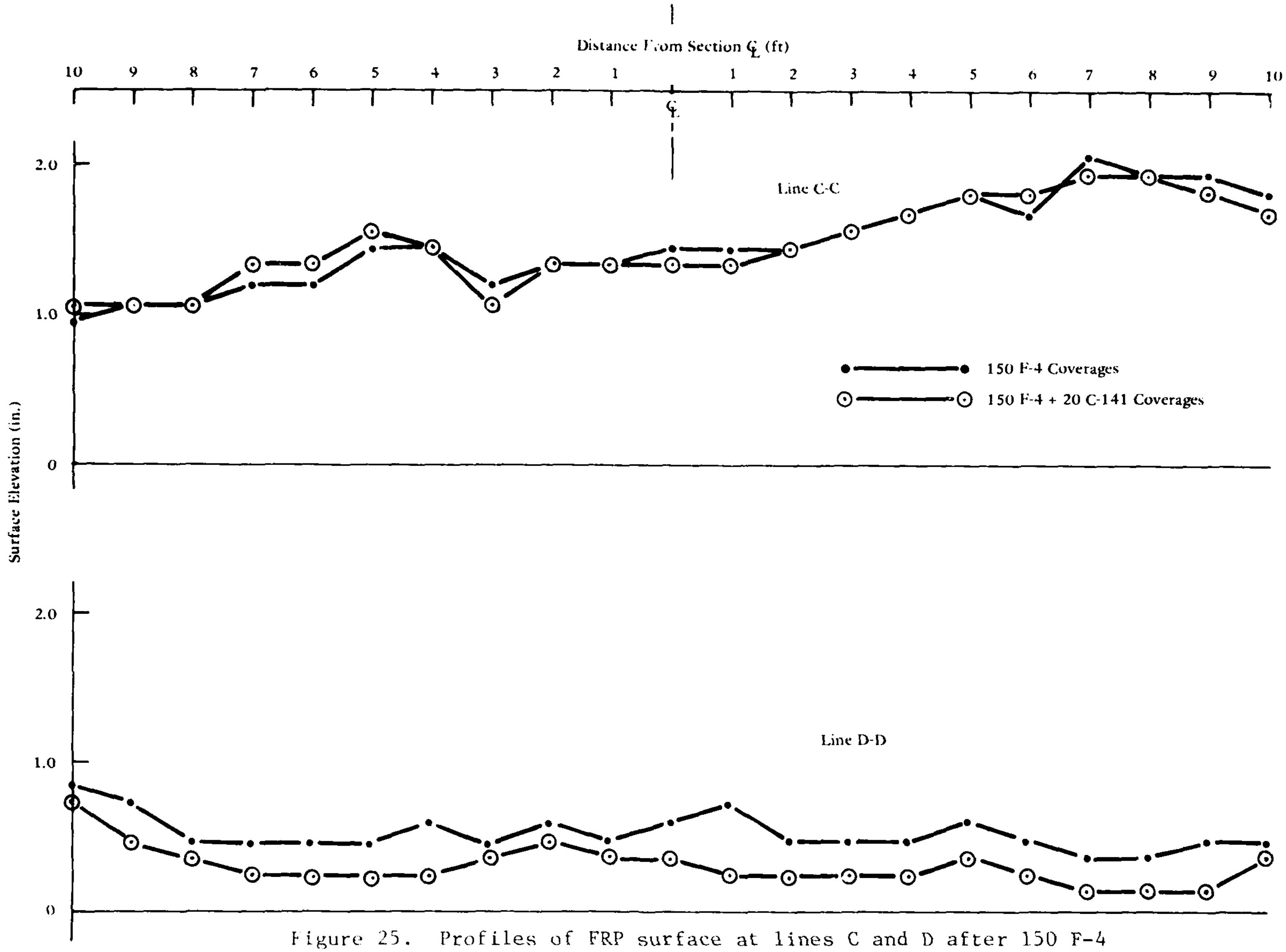

Figure 25. Profiles of FRP surface at lines C and D after 150 F-4 coverages and 20 C-141 coverages.

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